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BEHAVIOR OF THERMAL INSULATIONS USED AS SUBSTRATES FOR ROOFING MEMBRANES

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INTRODUCTION:

Roofing insulation has long been considered important for the insulation of buildings and consequently, for the comfort of the occupants.

Its significance has been heightened by recent events which make improved insulation even more necessary to conserve energy.

At the present time, most roof designs include:

- a strucutral supporting member
- a layer of thermal insulation
- a waterproof covering, loosely laid or adhered.

This design, with adhesive waterproofing, is the one which has been applied for over twenty years to metallic roofing and is very common in France on industrial buildings. It has also been applied for a decade to concrete roofs, for which there has been a progressive change from the adhesive systems to loose, ballasted systems.

Even though this concept appears to be effective in protecting the structures from the effects of temperature variations, it also poses problems and has given way to disasters connected with the behavior of the waterproofing and insulating system.

These problems have arisen primarily from the lack of knowledge about insulating materials used and their potential for being used in conjunction with a waterproof covering.

Since the maket offers a wide choice of insulating materials and waterproof coverings, as well as different methods of bonding them, there would be a risk if the materials were selected in an anarchistic manner. We designed an experiment to predict the behavior of the systems considered, in such a way as to proceed to the necessary choices in a logical manner.

The primary emphasis is on the study of differential movements.

This study is limited to the analysis of the movements of the insulation which are a base for an independent waterproofing, and to their possible effects on the covering, under the influence of outside temperature variations and sunshine.

It is a continuation of the study presented on the same topic at the International Symposium on Roofs and Roofing, Brighton, 1974.

MEASUREMENT OF THE MOVEMENT OF THE BALLASTED INDEPENDENT WATERPROOF-BASE INSULATION

1. Principle

The dimensional variations of the surface of the insulating panels in use (in contact with the waterproofing) are different from those which could be measured on totally free pieces, for the following reasons:

- the temperature is not uniform in the breadth of the panels in use but decreases from top to bottom;
- the adhesion on the underside restrains the movement, this restraint being in terms of the width and the quality of the adhesion;
- the friction of the membrane restrains the movement in terms of the conditions of the opposite surfaces, its own weight and the added weight.

The pressure exerted by the membrane on the insulation is equal to that exerted by the insulation on the membrane. The visible and measurable effect of this is the reduction of surface movement of the covered panels in relation to the uncovered panels, all else being equal. The simplified mathematical equation is given in Section 2. It shows that the measurement of the reduction of displacement of the ends of the panels (i.e., the variation of the opening of the joint between panels) constitutes an indirect measurement of the restraint in the membrane.

2. Simplified Mathematical Formula of the Pressure Transmitted to the Independent Waterproof coverings by the Movement of the Base Insulations Directly Related to the Variations of Their Surface Temperature

By definition, if V is the relative displacement of the point of abscissa x and α the coefficient of thermal expansion on the surface of the panels,

$V = \alpha \times \Delta\theta$ for a variation $\Delta\theta$ of the surface temperature (1)

By definition, if G is the modulus of transverse flexibility of the panel with breadth base e, the stress produced in order to obtain a relative displacement V of a surface s (length dx width unit) of one side in relation to the other is:

$$df = \frac{G}{e} \alpha \Delta\theta x \, dx$$

$$\text{giving } df = \frac{G}{e} \alpha \Delta\theta \frac{x^2}{2} + C$$

$$\text{and } f = \frac{G}{e} \alpha \Delta\theta \frac{x^2}{2} + C$$

The stress on the end of the linear panel 2L is

$$fl = \frac{G}{e} \alpha \Delta\theta \frac{1^2}{2} \quad (2)$$

If, all else being equal, the displacements of the end of the panel V_l measured without waterproofing and V_l measured with waterproofing are different, it is due to the fact that the friction θ exerted by the waterproofing on the surface of the insulation produces a stress

$$fl = \frac{G}{2e} \Delta\theta (L - L^1) 1^2 \quad (3)$$

3. Experimental Method

The method consists of measuring the movements of uncovered insulating panels (movements pertaining to width and length of the panels, and then adhesive quality), and under the same conditions, the movements of coated panels.

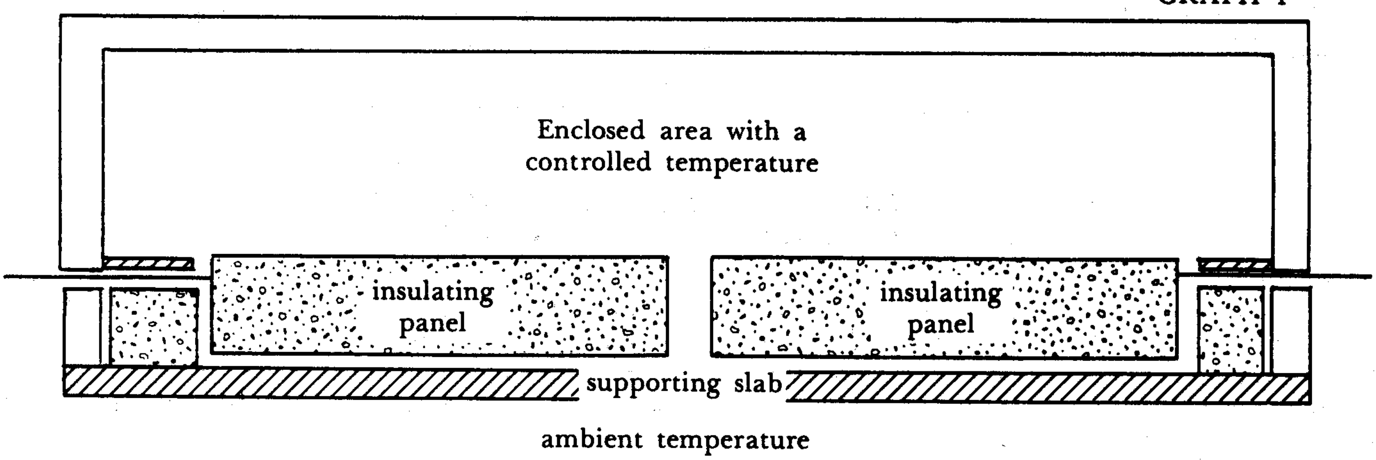
3.1 Experimental device

The experimental device used for the measurement of the variations of the opening of the joint between panels is as follows:

MEASUREMENT OF THE DIMENSIONAL VARIATIONS ON THE SURFACE OF WATERPROOF-BASE INSULATING PANELS

3.11 Model For Clear-Surface Panels

GRAPH 1



The model consists of two insulating panels (commercial length, width 20 or 50 cm) which adhere to hot asphalt on a supporting slab with a center having an initial width of 3 mm.

The insulating panels do not adhere to the supporting slab and have freedom of movement. Adhesion is limited to a small central area in order to avoid chaotic displacement.

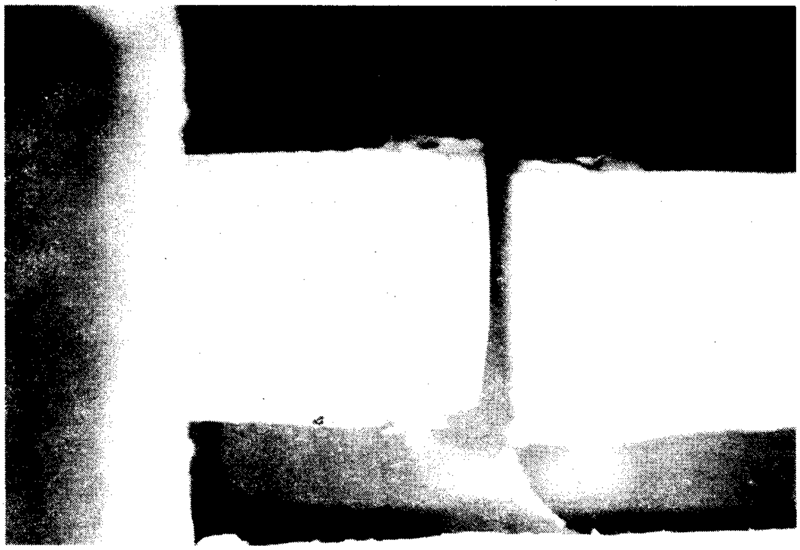
The variations in the length of the panels are measured at the ends and at the joint as soon as the temperature is stabilized.

The measuring instrument is:

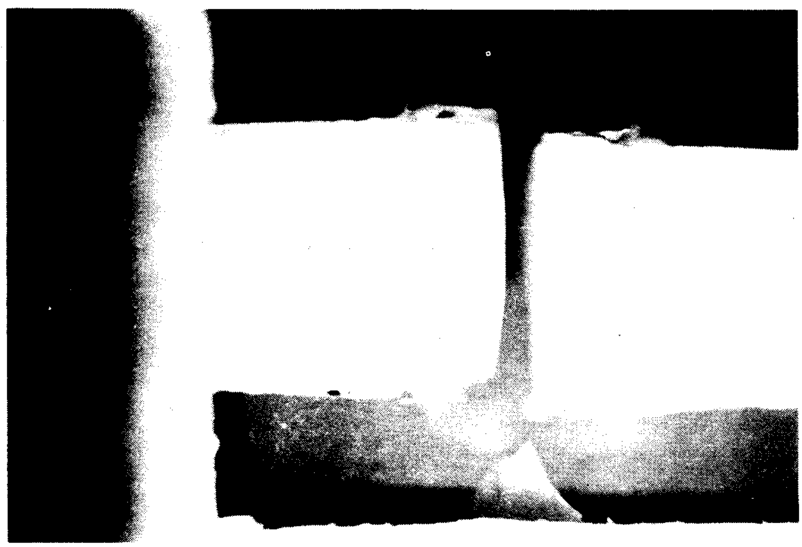
- at each end, a comparator at 0.01 mm
- at the center joint, a magnifying glass 40 graduated at 0.01 mm, reading the distance between two reference points connected to the insulating panels.

The following photographs illustrate the width variation of the joint between unadhesive polystyrene panels.

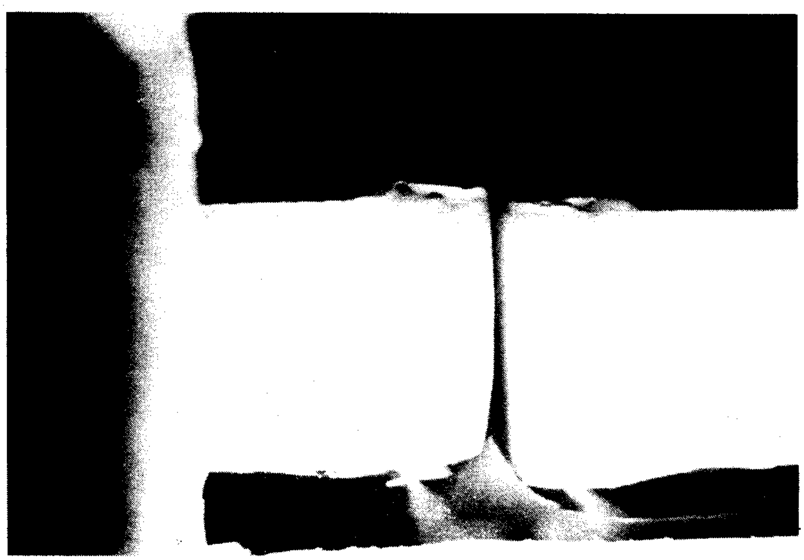
VARIATION OF THE OPENING OF THE JOINT BETWEEN UNCOATED INSULATING PANELS SUBJECTED TO THE AFOREMENTIONED EXPERIMENTAL CONDITIONS.



Opening of the joint at room temperature 13°C



Opening of the joint for a surface temperature of − 10°C

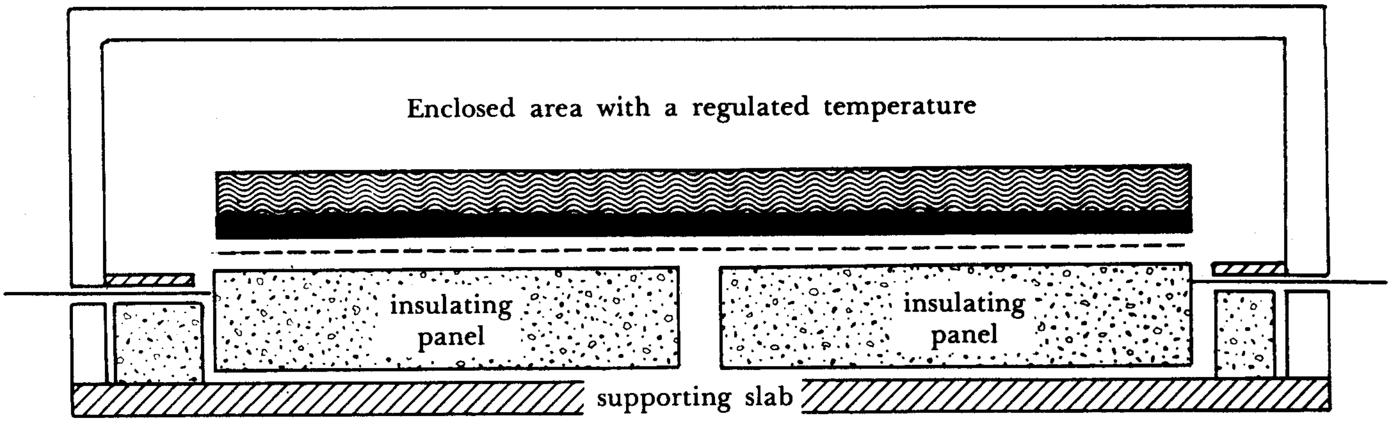


Opening of the joint for a surface temperature of 60°C

MEASUREMENT OF THE DIMENSIONAL VARIATIONS OF THE SURFACE OF WATERPROOF-BASE INSULATING PANELS

3.12 **Model For Independent Waterproof-Coated Panels**

GRAPH 2



ambient temperature

The model is coated with a standard waterproofing system placed on a loose underlying layer. It is ballasted with a layer of fine gravel 4 cm thick in the case of standard insulation, 6 cm in the case of heavy insulation (K on the order of 0.5 $W/m^2\,°C$) maintained in a wooden frame.

The underside of the supporting slab has a temperature of 10 to 20°C.

The surface temperature of the insulation varies cyclically from - 10°C to 60°C measured on the surface of the panels (under the waterproofing).

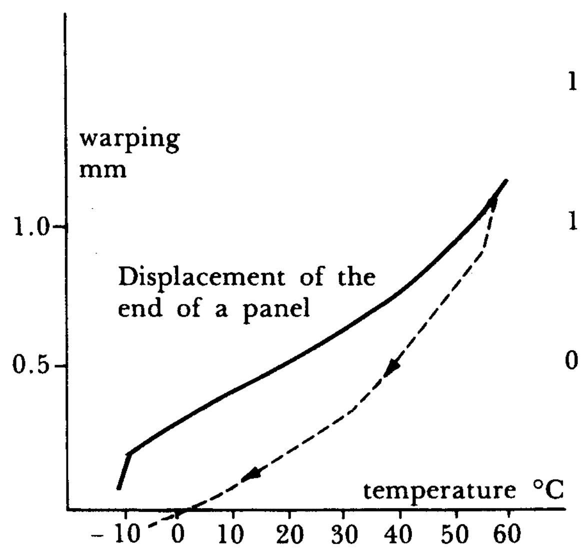
The variations in the length of the panels are measured at the ends and at the joint, as soon as the temperature is stabilized.

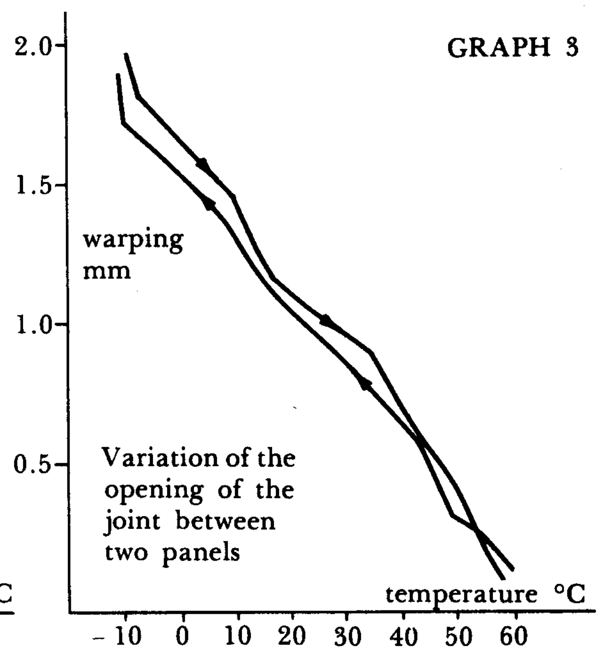
The measuring instrument is:

- at each end, a comparator at 0.01 mm
- at the center joint, a magnifying glass graduated at 0.01 mm reading the distance between two points of reference connected to the insulating panels.

Graph 3 shows the rate of the variation of openings of the joints (for polystyrene panels). The movement of the panels is listed as a function of the instantaneous variations of the surface temperature.

GRAPH 3





DIMENSIONAL VARIATION OF THE SURFACE OF THE WATER-PROOF-BASED INSULATING PANELS

Polystyrene panels

3.2 Results

At each low (- 10°C) and high (60°C) temperature level the variation of the opening of the joint with relation to the initial opening is measured and recorded on a graph.

The movements of the opening of the joint are designated by the + sign and those of the closing by the - sign.

For each test and in terms of the number of cycles, two more or less parallel lines are obtained, one representing the closing of the joint under heat, the other representing the opening of the joint when cold, always in relation to the initial opening reference 0 (graph 4).

The distance between the two lines indicates the extent of the total movement during the course of a cycle, between extreme high and low temperatures, this movement being reversible.

In addition, the residual warping of the panels (irreversible) is evidenced by the alteration of the opening of the joint at a given temperature, in proportion to the progression of the cycles.

Finally, only the variations in the opening of the joint between two panels are represented. The variations at the ends are noted during the course of the test and are generally identical to the imprecision of close measurement.

3.3 Significant feature of the variations of the opening

The inaccuracy of reading the micrometer is along the order of 2/100 mm. The imprecision concerning the variation of the opening of the joint is thus 8/100 or 1/10 mm.

The variations of the opening >0.1 mm can therefore be considered significant. The other sources of variations are:

- the surrounding temperature on the underside of the slab;
- the temperature of the surface of the insulation at the time of measurement which can, in practice, vary between 55 and 62°C or - 12 and - 6°C, for it is not always possible to introduce two temperature levels during a lapse of 8 hours. A temperature correction was not made on the graphic representations.

4. RESULTS

4.1 Kinds of movements presented relative to the composition of the materials

Essentially the following kinds of movements are noted in the drawing of the panels:

a) Irreversible movements, of such a nature that the warping is permanent even if there is a return to the conditions of the initial humidity and temperature. This is the case with shrinkage by internal restructurings of plastic materials whether reticulated or not.

b) Reversible movements, of such a nature that the warping is removed by the return to the initial conditions. To be differentiated:

b.1.) Reversible movements related to the hygrometric condition of the material. This is the case with shrinkage by drying and swelling the cellulose matter by humidification. These materials generally show signs of a certain inertia from this point of view; the effect of the temperature variations is lessened, and the regular recurrence of the movements to the maximum extent is mostly seasonal.

b.2.) Reversible movements directly related (proportionally and simultaneously) to temperature variations. Since the temperature may vary frequently and rapidly, these movements are frequent and rapid. This is still the case, particularly for plastic alveolar materials whether reticulated or not. It's fundamentally this type of movement which is examined in the present analysis.

4.2 Consequences of the frequent and rapid movements of the bases on the independent waterproofing.

Stress on the right angles of the joints of the bases was analyzed in terms of the composition of the materials.

It has been shown that:

- the friction under independent waterproofing has the effect of reducing the surface warping of the base, which creates a state of restraint in the waterproofing;
- the pressure exerted at the right angles of the joints on each panel is explained by (Section 2, Equation 3):

$$fl = \frac{G}{2e} \Delta\theta \, (L - L^1) \, l^2$$

where G = apparent drying modulus of the panels
e = breadth of the panels
$\Delta\theta$ = temperature variation
LL^1 = apparent coefficients of superficial expansion of the panels, before and after laying the waterproofing
l = half-length of the panels

The experimental method allows direct measurement of the possible warping (without waterproofing), and, consequently, the calculation of the apparent coefficients of surface expansion L potential and L^1.

Table II summarizes the results which are illustrated by graph 8 (cellulose perlite), 9 (paper polyurethane), 10-11-12 (expanded polystyrene), and 13-14 (extruded polystyrene).

From the projected technical solutions, the use of polystyrenes obviously presents the most risks and causes concern, especially since its use is the most economical.

4.3 Influence of the adhesion of the insulation

Two classifications of adhesion have been adopted:

- satisfactory adhesion
  that is, the underside of the insulation is evenly adhered to the hot asphalt on the supporting slab.
- unsatisfactory adhesion
  that is, the underside of the insulation only adheres to the supporting slab half the length of the panel, on approximately 10 cm, the rest of the panel being loose on a sliding layer.

A reduction in surface movements is anticipated from satisfactory adhesion. Since the cutting restraint is proportional to G, it can be predicted that the adhesive effect should be diminished when the breadth increases.

Table III summarizes the values $L\text{-}L^1$ and their distance from each other for different thicknesses of homogeneous polystyrene which is satisfactorily or unsatisfactorily adhesive (x 10^5).

The experimental measurement confirms that the effect of the adhesion diminishes when the thickness increases and becomes practically negligible for thicknesses of 100 mm.

Indeed, it is known that the coefficient L of thermal expansion of the free-moving material is along the lines of 5 to 6×10^{-5} °C^{-1}.

It is this value that is measured on non-adhesive uncoated panels, which is standard.

It is also this value which is measured on satisfactorily-adhered uncoated panels having a thickness of 100 mm.

These findings are illustrated by graphs no. 10 (40 mm satisfactorily and unsatisfactorily-adhesive), 13 and 14 (60 mm satisfactorily and unsatisfactorily-adhesive), 12 (80 mm unsatisfactorily-adhesive) and 11 (100 mm satisfactorily-adhesive).

The law of variation of the movements in terms of the quality of the adhesion of the underside and of the thickness can thus be expressed (graph 15) for the polystyrene panels.

For the other types of panels, the chances are not good for obtaining an experimental verification of this law, taking into account the precise nature of the measurements.

In fact:

- other types of panels show signs of movements of a much smaller magnitude.
- their thicknesses vary less.

4.4. Application to composite materials

By composite insulation materials I mean panels with two layers of different composition, industrially prefabricated (industrial composites) or superimposed in situ (reconstituted composites).

Generally used are:

- polyurethane foam for one of the layers
- an insulating mineral (fiberglass) or perlite-cellulose for the second layers.

According to use, one side or the other can be a waterproof base.

The experiment reveals that these panels react, from the point of view of the differential movements, in a way nearly identical to the homogenous panel of the same waterproof-base composition.

Thus, there is no reason to distinguish them, from this point of view, from the cellulose perlite or polyurethane homogenous panels already listed.

These results are illustrated by the following graphs:

- Graph 16: Reconstituted composite PUR – Perlite-Cellulose, compares with graph 5, panels of cellulose perlite.
- Graph 17: Industrial composite PUR – Cellulose Perlite, likewise compares with graph 5.
- Graph 18: Cellulose perlite industrial composite PUR compares with graph 9, paper PUR panels.
- Graph 19: Fiberglass industrial composite – PUR-glass sheeting likewise compares with graph 9.

CONCLUSION

We examined one kind of problem related to the use of insulating panels as roofing waterproof bases. It is not, of course, the only one, but in our opinion, one of the important ones if it is seen from the point of view of the durability of the roofing system.

The approach taken still leaves a number of questions unanswered, but it cannot fail to attract attention to the differential movements between waterproof coatings and bases and the consequences which follow from this concerning the behavior of the coatings. The means of evaluating the stress transmitted to the coating should not be considered as rigidly set up on an absolute value, but it can constitute, here and now, a useful basis of comparison between the possible risks which one particular system would present in relation to another.

This approach reveals, in addition, that the conditions of construction, for example, the quality of the adhesion of the insulating panels and the quality of the looseness between panels and insulation, can exercise a determining influence on the behavior of the finished product.

It is necessary in this respect to resort to a total consideration of the insulating-waterproof coatings system, a consideration in which experimentation must have an important place.

On the practical level, this means that a thorough evaluation can only proceed from a collaboration between manufacturers of insulation, manufacturers of waterproof coatings, applicators, and project managers; that is, all those participating in the building activity.

TABLE 1 - TYPE AND EXTENT OF THE MOVEMENTS UNDER THE MEMBRANE, ACCORDING TO THE INSULATION

Composition of the insulation in contact with the membrane	Variation of the opening of the joint between panels (mm)			Observation
	Slow, reversible movement	Rapid, reversible movement	irreversible movement	
Cellulose base Cellulose Perlite Type	1 to 2	0.1 to 0.2	——	
Expanded Polystyrene Base	——	0.5 to 4	0 to 2.5	According to manufacturing process
Paper-Lined or Asphalt Roofing Felt Polyurethane Base	——	0.2 to 0.6	3	

By way of example, the following graphs illustrate the kinds of irreversible and slow and rapid reversible dimensional variations for panels with a base of:

- Cellulose perlite (slow reversible) - Graph 5
- Expanded polystytene (irrversible and rapid reversible) - Graph 6
- Permeated asphalt-surfaced polyurethane (slow irreversible) - Graph 7

TABLE 2 - EVALUATION OF THE PRESSURE EXERTED ON THE INDEPENDENT WATER-PROOFING UNDER THE INFLUENCE OF FREQUENT TEMPERATURE CHANGES, ACCORDING TO THE COMPOSITION OF THE INSULATION.

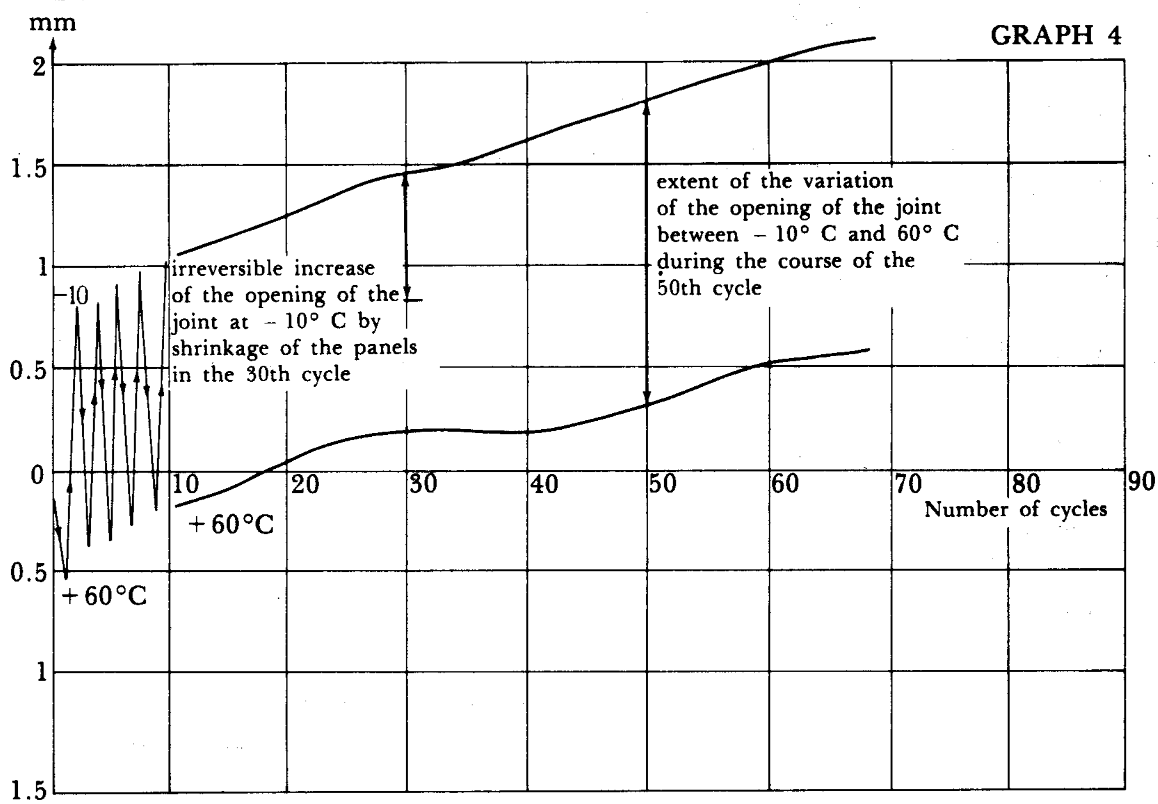
Composition of the insulation	L apparent experimental on the surface of the panels		$L - L^{1}$	Estimated pressure on the right angle of the joint for $\Delta\Theta = 35°C$ $2 F_L$ kg/cm
	Uncoated $L\,10^{5}$	Coated $L^{1}10^{5}$		
Perlite-cellulose 2 1: 90 cm (Graph 8)	0.1 to 0.2	0.1 to 0.2	incalculable	≃0
Paper-lined polyurethane 2 1: 100 cm e: 40 mm (Graph 9)	1.4	1.3	0.1	0.3
Expanded polystyrene 2 1: 100 cm e: 40 mm good adhesion e: 40 mm poor adhesion (Graph 10)	2.6 4.3	2.4 2.6	0.2 1.7	0.7 6
Expanded polystyrene 2 1: 100 cm e: 100 mm good adhesion (Graph 11)	4.8 4.0	3.1 2.7	1.7 1.3	2.4 2.2
Polystyrene expanded by the Dry Method 2 1: 120 cm e: 80 mm poor adhesion (Graph 12)	5.6	3.4	2.2	4
Extruded polystyrene 2 1: 125 cm e: 60 mm good adhesion (Graph 13)	3.4	2.2	1.2	6
Extruded polystyrene 2 1: 125 cm e: 60 mm poor adhesion (Graph 14)	4.4	2.9	1.5	8

TABLE 3

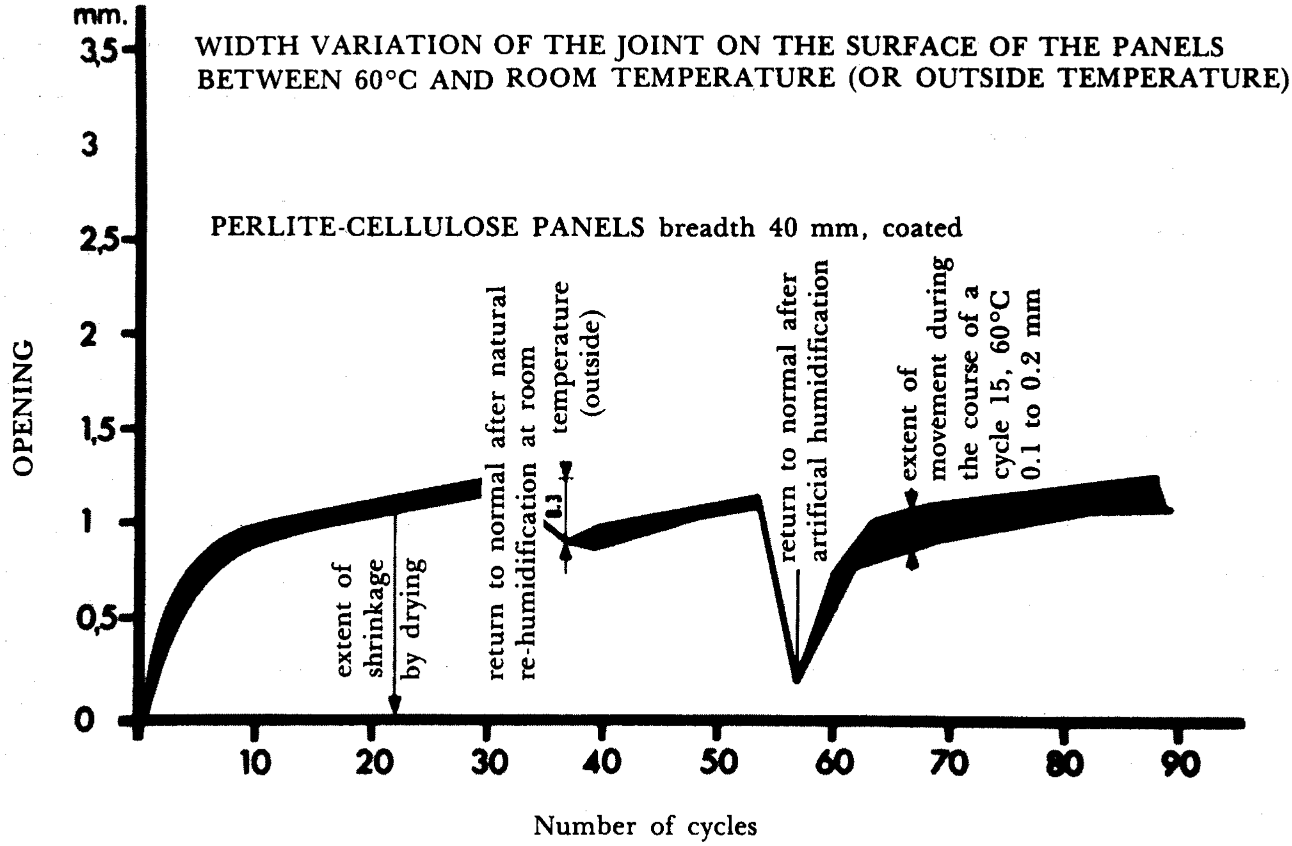
Composition and Breadth of the Polystyrene	Good Adhesion			No Adhesion		
	L	L[1]	L-L[1]	L	L[1]	L-L[1]
PS blocks 40 mm (Graph 10)	2.6	2.4	0.2	4.3	2.6	1.7
Extruded PS 60 mm (Graphs 13 & 14)	3.4	2.1	1.3	4 to 4.9	3.0	1.5
Dry Method PS 80 mm (Graph 12)				5.7	4.0	1.7
PS Block 100 mm (Graph 11)	4.8	3.1	1.7			

WIDTH VARIATION OF THE JOINT ON THE SURFACE OF THE PANELS BETWEEN 60°C AND - 10°C

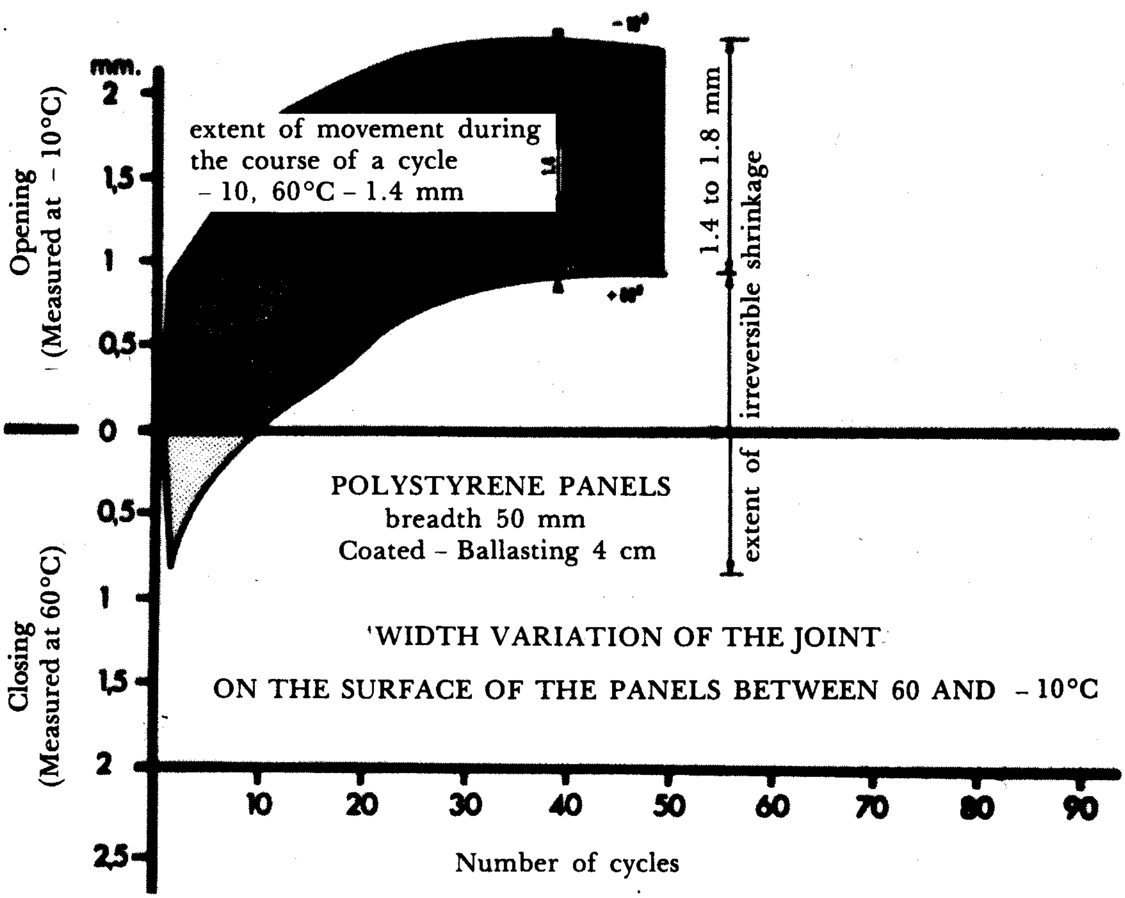
GRAPH 4

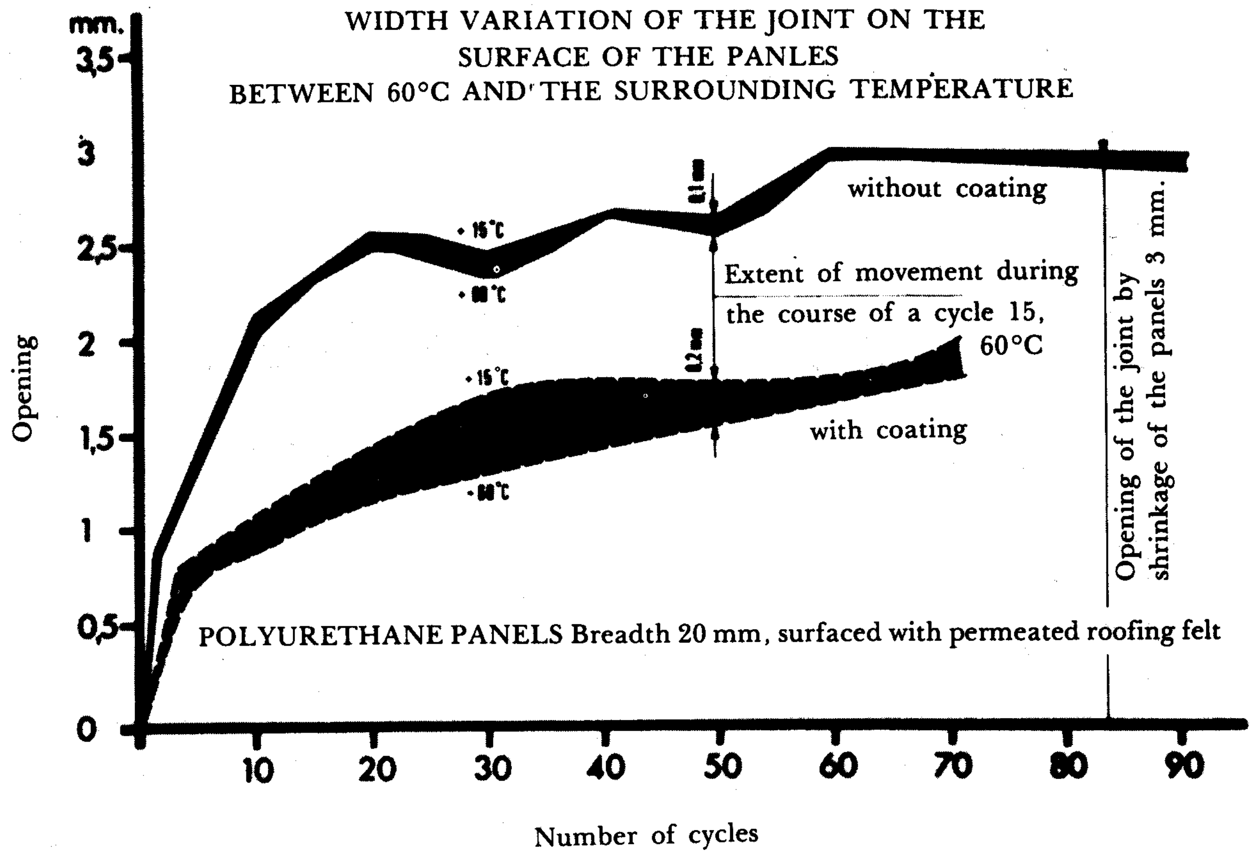


GRAPH 5

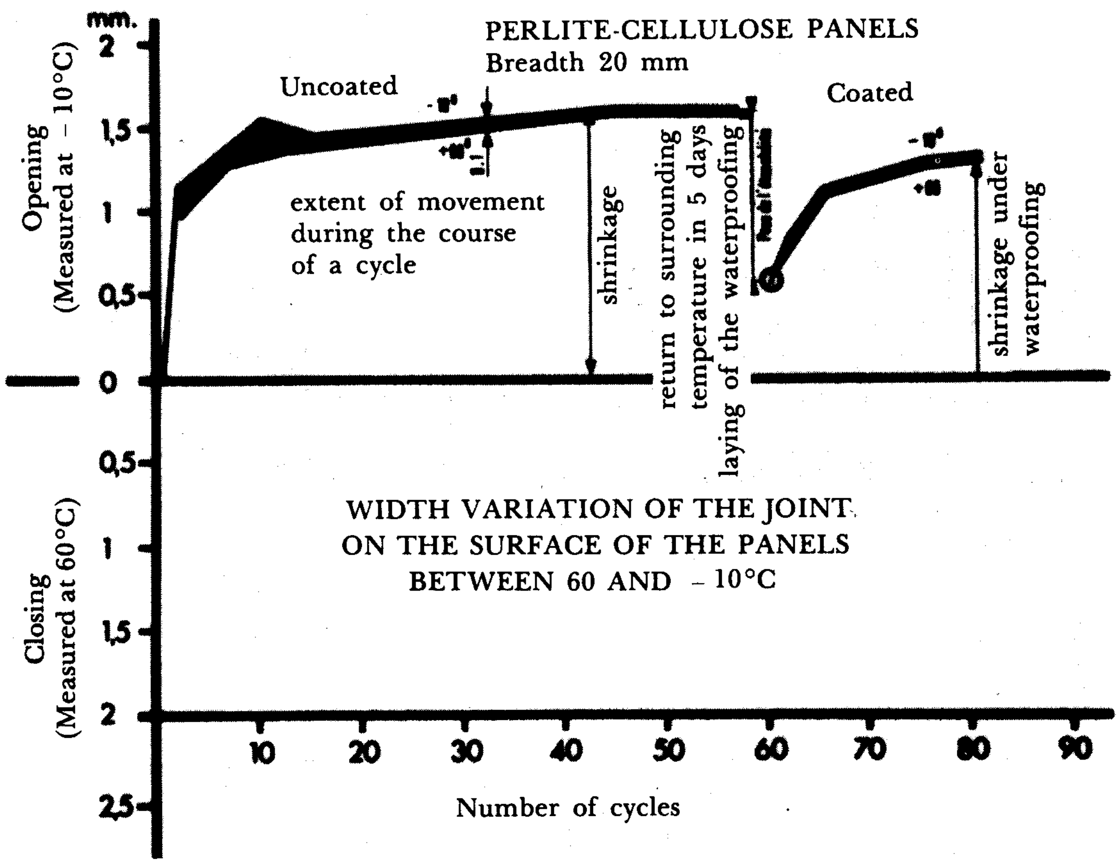


GRAPH 6

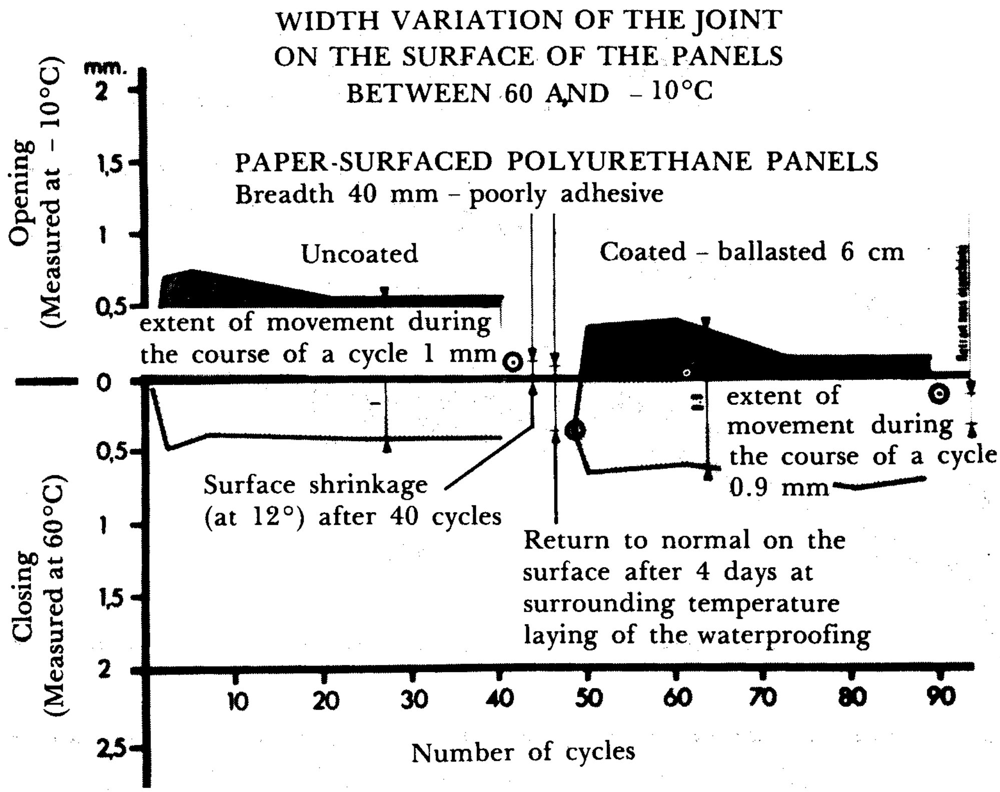



WIDTH VARIATION OF THE JOINT ON THE
SURFACE OF THE PANLES
BETWEEN 60°C AND THE SURROUNDING TEMPERATURE
mm.
3,5
3
2,5
2
1,5
1
0,5
0
Opening
without coating
Extent of movement during
the course of a cycle 15,
60°C
with coating
Opening of the joint by
shrinkage of the panels 3 mm.
POLYURETHANE PANELS Breadth 20 mm, surfaced with permeated roofing felt
10
20
30
40
50
60
70
80
90
Number of cycles

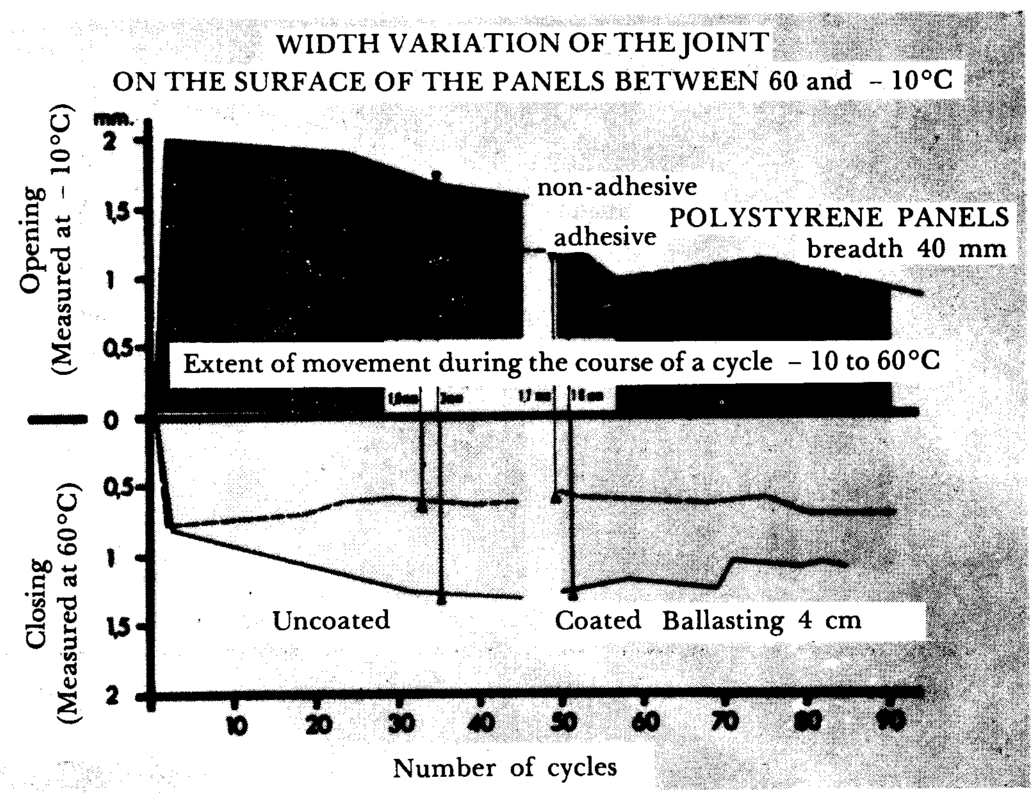
GRAPH 8


PERLITE-CELLULOSE PANELS
Breadth 20 mm
mm.
2
1,5
1
0,5
0
0,5
1
1,5
2
2,5
Opening
(Measured at – 10°C)
Closing
(Measured at 60°C)
Uncoated
Coated
extent of movement
during the course
of a cycle
shrinkage
return to surrounding
temperature in 5 days
laying of the waterproofing
shrinkage under
waterproofing
WIDTH VARIATION OF THE JOINT
ON THE SURFACE OF THE PANELS
BETWEEN 60 AND – 10°C
10
20
30
40
50
60
70
80
90
Number of cycles

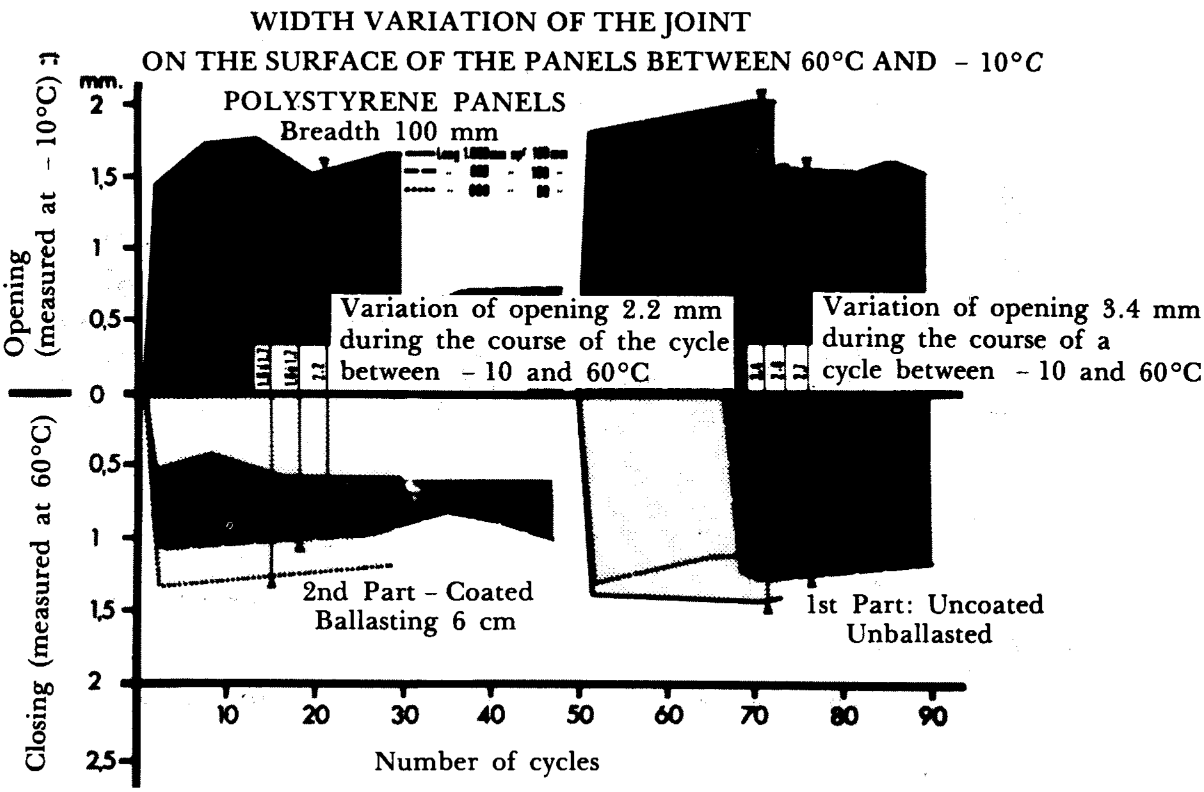
GRAPH 9



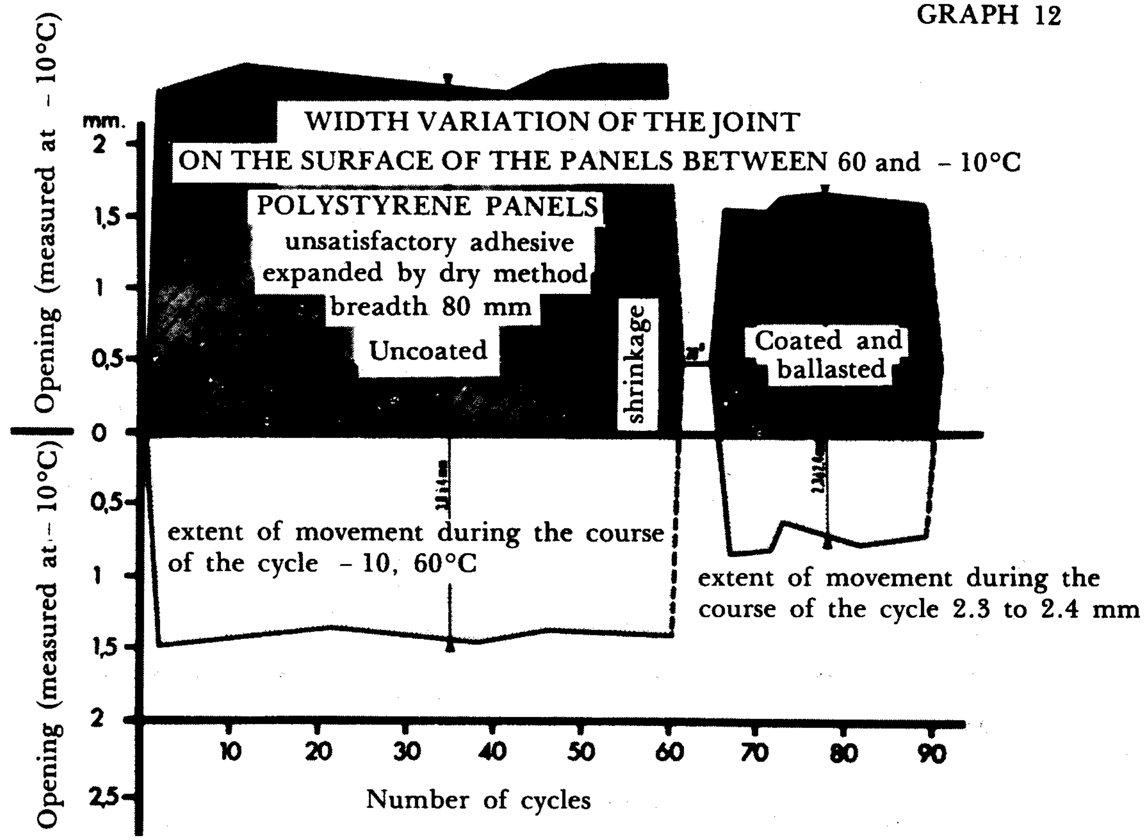
GRAPH 10



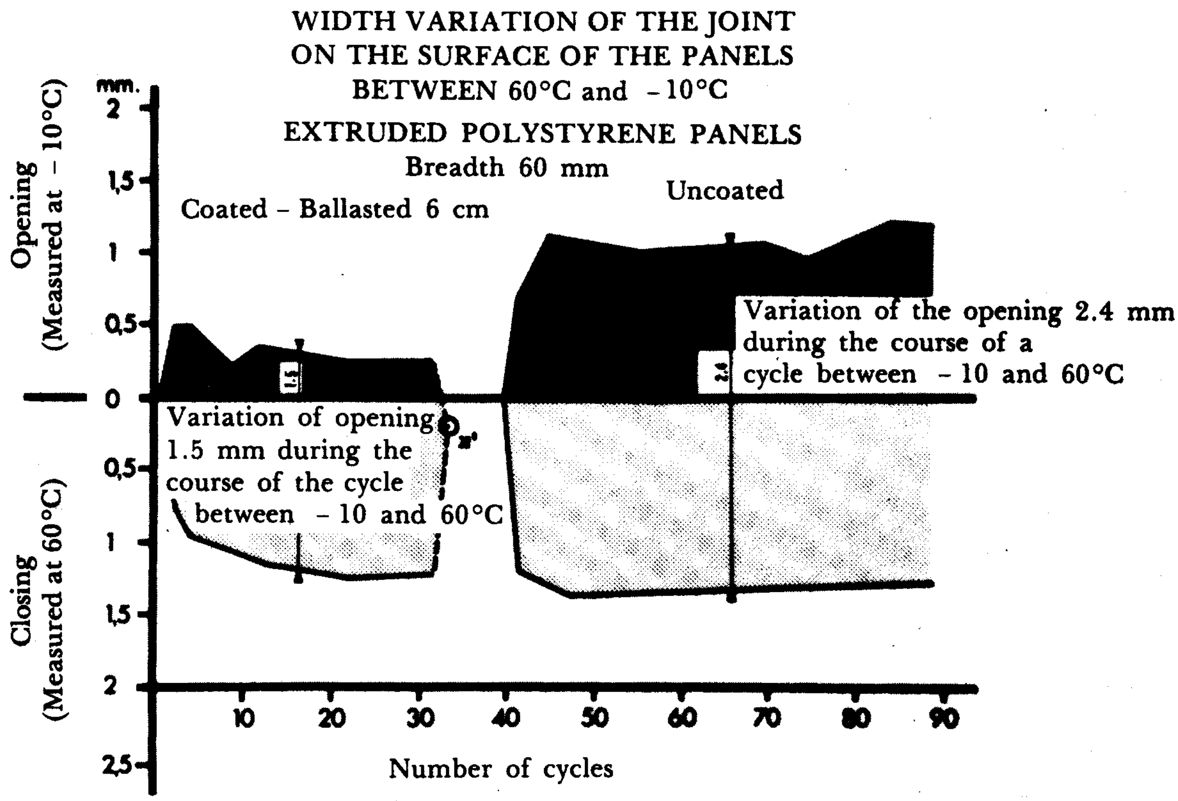
GRAPH 11



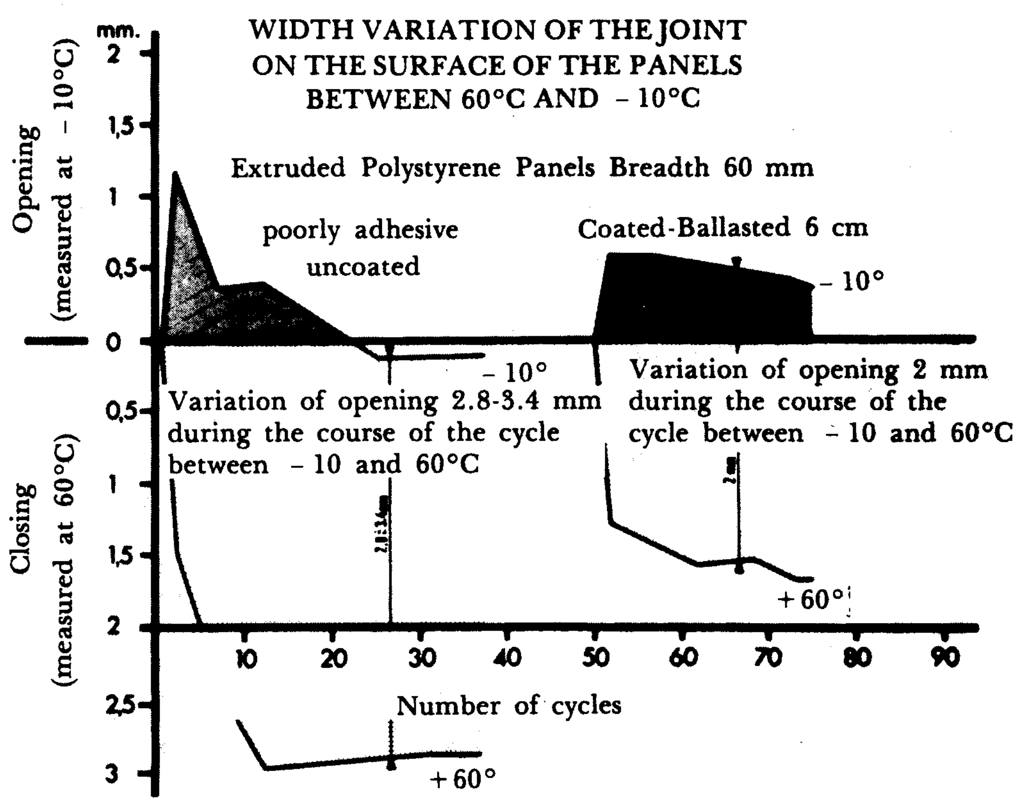
GRAPH 12



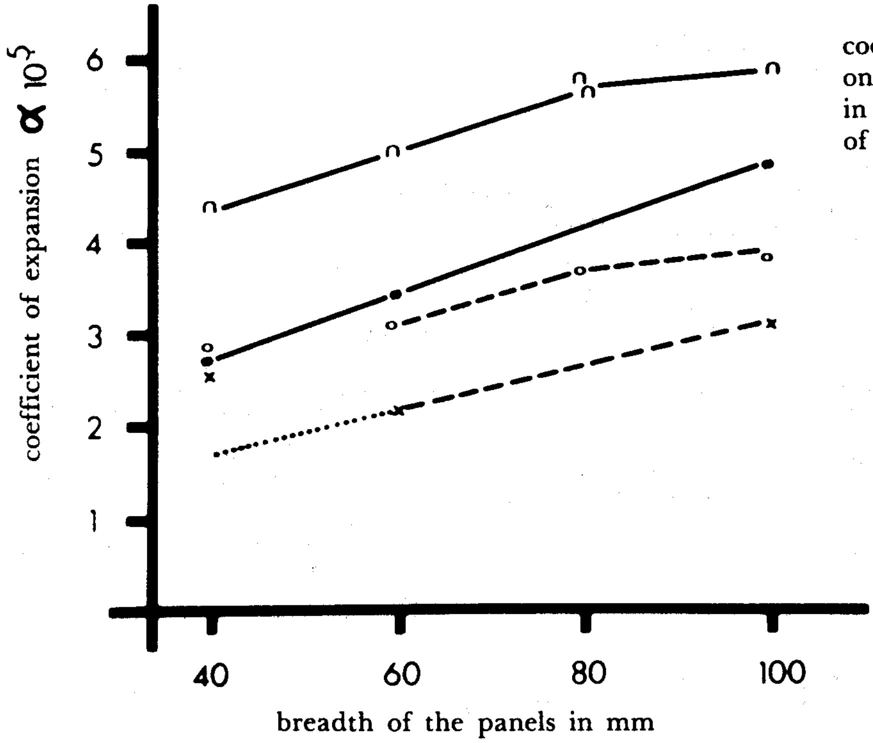
GRAPH 13



GRAPH 14



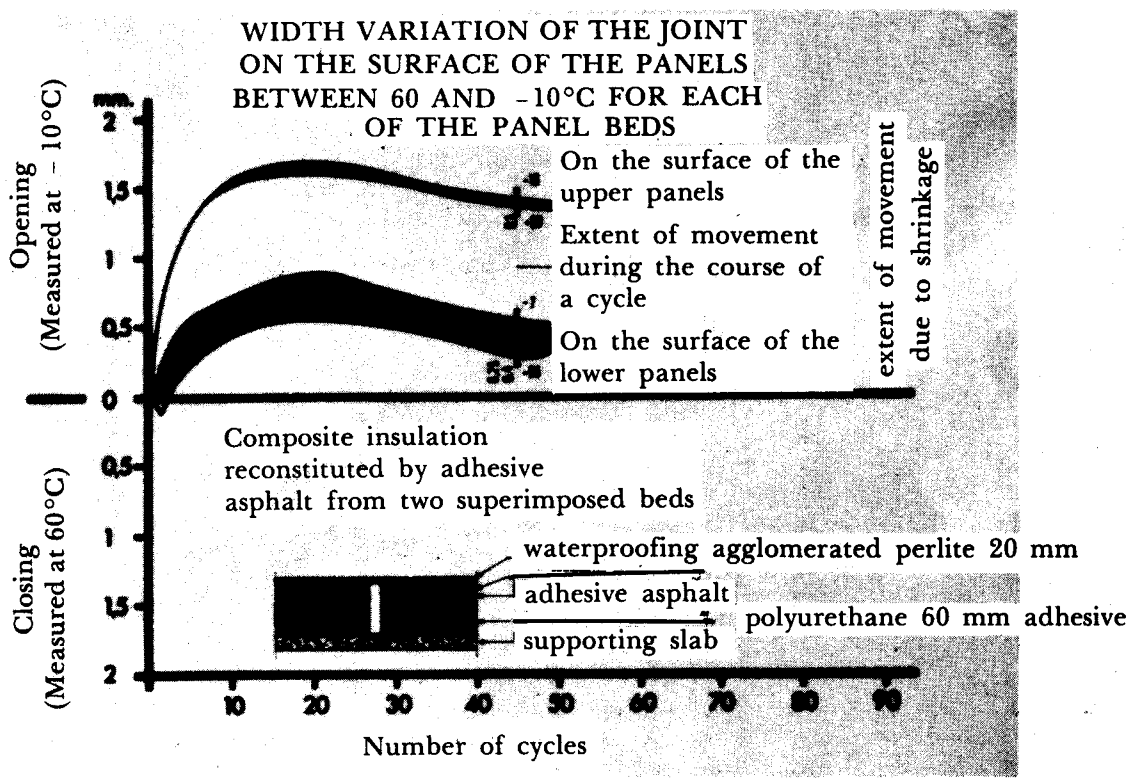
GRAPH 15



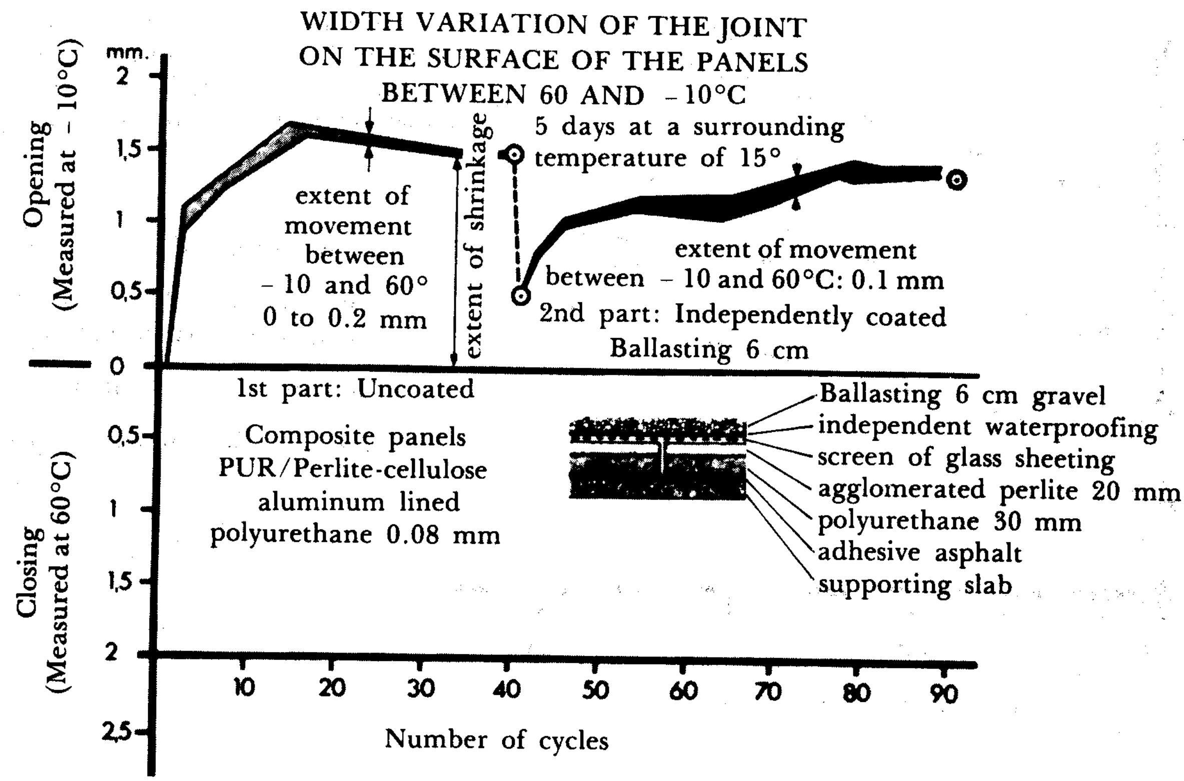
coefficient of apparent thermal expansion on the surface of polystyrene panels in terms of their breadth and the quality of their adherence to the supporting slab

- • satisfactorily adhesive, uncoated
- × satisfactorily adhesive, under independent waterproofing
- ∩ non-adhesive, uncoated
- o non-adhesive, under independent waterproofing

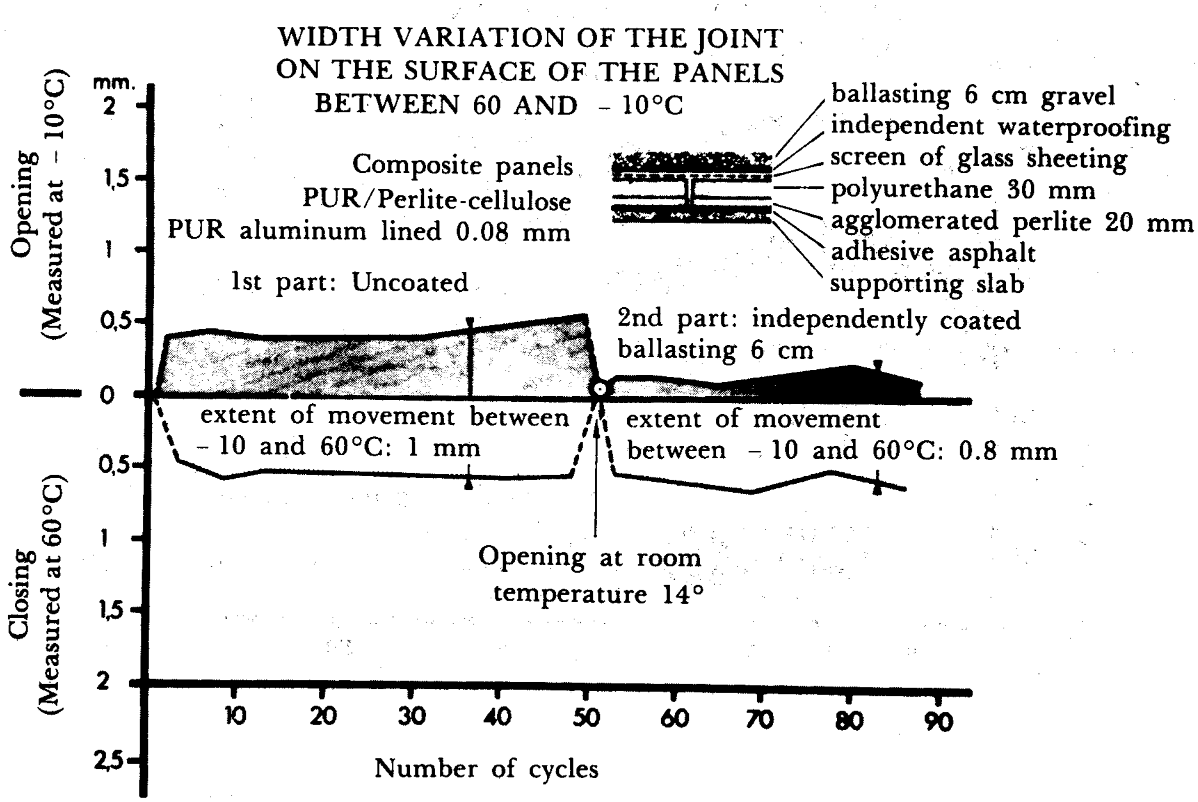
GRAPH 16



GRAPH 17



GRAPH 18



GRAPH 19

WIDTH VARIATION OF THE JOINT
ON THE SURFACE OF THE PANELS BETWEEN 60 and - 10°C